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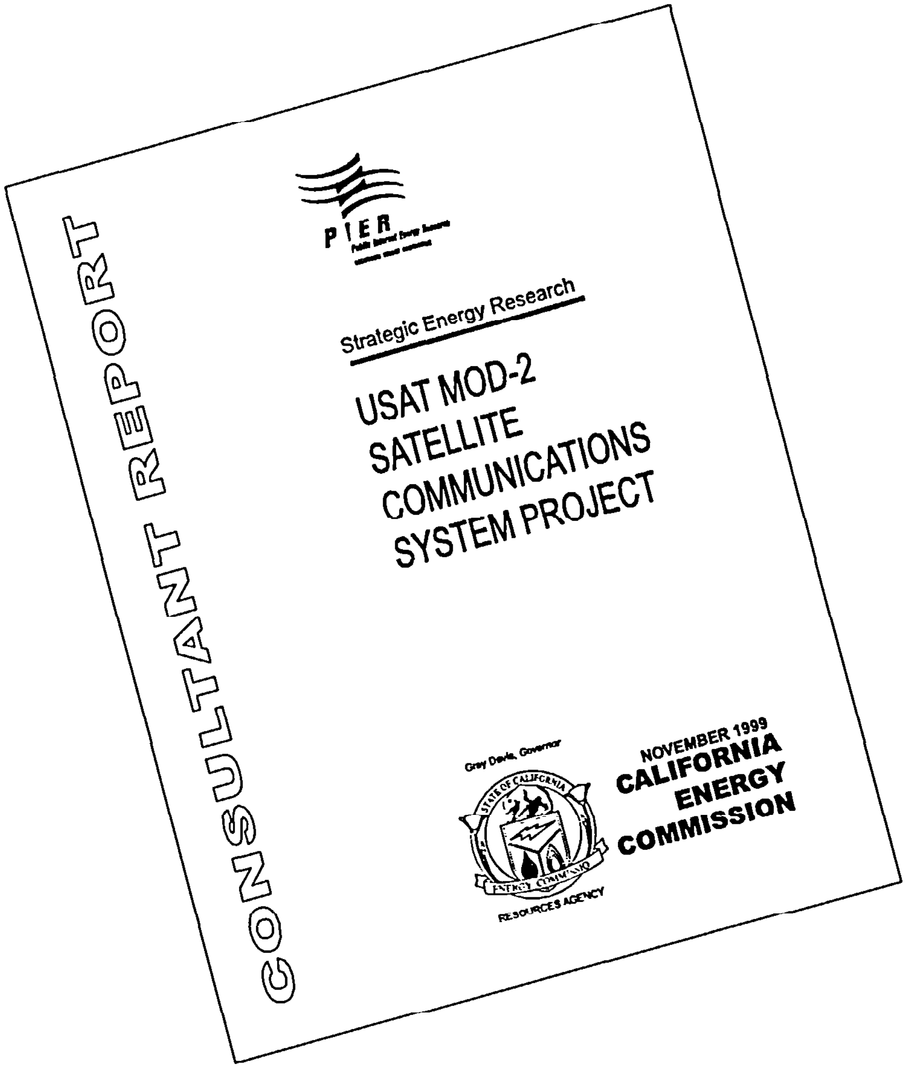

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

What follows is the final report for the Substation Reliability project, one of five projects conducted by Southern California Edison. This project contributes to the Strategic Energy Research program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

In a deregulated environment, increased substation monitoring and control automation to maximize usage of transmission and distribution assets is critical. Automated monitoring and control has a dual purpose:

- Allows operation of power networks at the highest reliability levels economically possible.
- Keeps pace with the tremendous volume of free-market energy transactions.

But the increased amount of data generated by the new monitoring and automation systems has a limited value if it is not correctly processed into usable information. Today in most cases, large amounts of raw data can easily inundate control room operators, hindering rather than helping reliable system operation.

Objectives

The objectives were to

- Demonstrate, under realistic conditions, the feasibility and potential benefits of intelligent alarm analysis and voice recognition technologies as means of alleviating the data processing problem.
- Evaluate voice recognition tools as a means of improving system reliability by freeing the operators' eyes and hands, improving their response time and effectiveness in taking remedial action.

Approach

A subcontractor, Hathaway Industrial Automation (HIA) developed the initial stage of the Alarm Analyzer tool. The Alarm Analyzer tool is an intelligent alarm analysis and diagnostics system that automatically classifies and filters thousands of pieces of information and alarms generated during an abnormal event on the grid.

For reasons of practicality and reliability, the demonstrations were performed off-line to avoid causing any disruption to the operating power system.

Equipment

The main hardware selected for the Alarm Analyzer system was the Hathaway DAS 4000 substation information server (SIS) and a Sun Workstation. The SIS contains the necessary protocols to interface with the relays and other monitoring devices with minimum customization. It has enough computational capacity in its calculator to process the analyzer's logic program.

Voice Recognition

The Voice Recognition demonstrations were performed at four different Southern California Edison (SCE) sites and involved three different applications. The sites were two substations (Lighthipe and Moorpark), the Compton Metropolitan Transmission Office, and the Rosemead facility. The three applications were the substation, the transmission field crew, and the office.

Lighthipe: Management requested development of four reporting forms to enable input of text directly by voice and the operators requested an electronic version of their scratch pads. Voice Connexion created a Visual Basic program using the Multiple Document Interface (MDI) feature. This program, known as Multi-Notes, is intended to replace the operators' pencils and paper scratch pads with voice-entered notes and to transfer selected notes into TaskMaster 4.0. MultiNotes.

Moorpark: SCE demonstrated the same four reports as were demonstrated at Lighthipe, but experienced software compatibility problems. For the majority of work in substation applications, direct voice entry into TaskMaster 4.0 was preferred to Multi-Notes. Except during peak workloads, Multi-Notes did not provide significant timesavings,

Compton Metropolitan Transition Office: The demonstration involved a field transmission line patrolman who inspects overhead lines and structures as he drives by. To fill out the required one-page form with comments, the patrolman has to either stop the vehicle or wait until he is back at his desk.

Voice input allowed all information to be entered on the form approximately three times faster than by hand. Accuracy was almost 100 percent. This application demonstrated that voice recognition technologies freed the inspector's hands and eyes and enabled multitasking. However, the patrolman and his supervisor expressed the opinion that the comments in the report are usually too short to warrant changing to voice input only.

Rosemead: This involved demonstrating an office application for a manager who was confined to a wheelchair with limited hand and arm mobility. The individual reported that the Via Voice system was accurate and easy to use. He said his productivity improved when using voice input for long documents. The primary drawback was that in a cubicle environment, there was too much distraction for effective voice input. The lack of privacy led to a feeling of self-consciousness.

Outcome

- The Alarm Analyzer accurately detected, located, and identified disturbances in both scenarios.
  - Reduced the time required to produce an accurate diagnostic of an event from several hours or days to less than 2 minutes.
  - Alarms generated were filtered and reduced in number from seven to one in all scenarios.
- The voice recognition tools increased productivity by at least 200 percent in entering information into a computer file.
  - Four reports could be completed by voice input in less than half the time needed by a touch typist using a keyboard and mouse.
  - A 97 percent accuracy was achieved. This improved with increased use of the program.

Benefits to California

- Improved power delivery system reliability resulting in increased safety and economic savings.
- Increased access to available low-cost energy resources.
- Environmental benefits include a decrease need to build generation and transmission lines.

Conclusions

- Voice data input has strong potential to improve productivity and accuracy. For control room operators and the patrolman, this could contribute to improved reliability at substations and lines.
- While the technology is ready for system-wide use, applications have to be judiciously selected, and implemented with care to avoid interface problems.

Recommendations

- A pilot project at a typical regional control center of the intelligent alarm analyzer is strongly recommended.
- The intelligent alarm analyzer's information on the type and location of the disturbance should be combined with an outage estimator system to generate an alert and inform the affected customers of the expected outage duration time.

Abstract

In a deregulated environment, increased substation monitoring and control automation is necessary to keep up with the tremendous volume of free-market energy transactions and to operate the power networks at the highest reliability levels economically possible. However, the increased amount of data generated by the new monitoring and automation systems overwhelms control room operators. To alleviate this problem, Southern California Edison (SCE) demonstrated the feasibility of an Alarm Analyzer tool and a voice recognition system. The Alarm Analyzer tool is an intelligent alarm analysis and diagnostics system that automatically classifies and filters the thousands of pieces of information and alarms generated during an abnormal event on the grid, such as a regional blackout caused by a fault. The project also implemented and evaluated a voice recognition technology for the entry of data and commands into computers or other devices in control rooms and other installations. Field demonstrations indicated that the intelligent alarm analyzer and voice recognition technologies have the potential to improve the quality of the decisions and streamline execution of the procedures followed by utility personnel in the field, the control room, and the office. The following conclusions were reached: Use of the Alarm Analyzer could reduce the time required to produce an accurate diagnostic of an event from several hours or days to less than two minutes. Voice recognition tools of the type evaluated in this project could realistically result in a productivity increase as high as 200 percent in entering information to a computer file with an error rate lower than three percent.

1.0 Introduction

1.1 Statement of the Problem

Electrical power delivery systems are an essential ingredient in the development of any modern society. Dependence on electricity is driven by the extensive and widespread use of equipment, appliances, and instrumentation that operate on electricity. Because of this growing dependence, when electric power flow is interrupted, the consequences can be catastrophic—not unlike the effects of cutting off the blood supply in a living being. It is therefore not surprising that traditionally an extraordinary amount of care has been exercised in the design, construction, and operation of electric power grids. Clearly, the largest systems with the highest reliability man has ever created are the electric power systems.

Key to achieving improved reliability rates for the complete power system, typically as high as 99.999 percent, is the reliable operation of substations and their corresponding equipment. It is at the substations that power is conditioned and directed under both normal and abnormal conditions. Substations function as control nodes in a grid where voltage transformations and current switching are performed.

Substations, in conjunction with electric generation plants, control the energy flows. As an example, a substation may have two bulk power or source lines and 5 to 15 distribution feeder circuits. This typical arrangement clearly indicates that it is much more effective and economical to implement reliability improvements at the substation level than in the individual circuits. The impact on both frequency and duration of service interruptions and on the number of users affected by these outages depends more on the manner in which substation components perform than on the performance of circuit components downstream.

Reliability degradation in the last decade has several causes. Clearly, United States power systems have reached the end of their service life. Many of the grids were built in the late 1940s and early 1950s to literally power the post-war economic boom. Additions and relatively small upgrades have accommodated the moderate-and low-load growth seen from about 1970 through the present. But the basic infrastructure has reached and passed middle age, and breakdowns have naturally increased. With the uncertainty and risk regarding ownership of the generation and grid assets, utilities have been hesitant to improve existing facilities or build new ones.

Direct access due to deregulation, and before that, the interconnection of third-party generation sources to the grid, have imposed electrical stresses on the system beyond its original design limits. For example, new plants were sited where it was convenient for the new owners in terms of initial investment and operating costs. Minimum regard was given to the effect of these plants on the reliability of the total power system, and no consideration was given to using these new plants to support the system during contingencies.

Furthermore, the operators in the new installations are less experienced than those in existing utilities. With the growing number of third-party generators and the spread of distributed generation, this condition will continue. Lastly, the motives and modes of operating the system have drastically changed from the traditional goal of safe and reliable service to that of profit above all else. The excessive number of regional-type blackouts and brownouts endured throughout the Nation during the last two summers testifies to the general decline in power system reliability.

The alternative solution of building additional generation and transmission lines is environmentally and economically unacceptable. Even if the costs were reasonable and the large amounts of needed capital available, society would not allow the destruction of the environment that would accompany new construction on a national scale. Direct replacement would be an alternative with much less environmental impact. Although it would be more expedient, the cost would still be high, since a simple direct replacement would result in only a small gain in capacity.

In the past, remedial actions performed in a coordinated manner by operators from various neighboring utilities worked well to avoid or at least limit regional outages. This was possible because the systems' design margins were respected and utilities were willing to collaborate on the solution of these and other mutual issues.

Today the approach adopted by many utilities is that of maximizing the usage of existing assets. The assumption is that safe and reliable operation closer to the margin can be achieved by increasing the amount of monitoring to better control the system. It is also assumed that the benefits derived from the increase in capacity obtained will outweigh the initial and ongoing costs of these monitoring systems.

1.2 Project Objectives

To maximize usage of transmission and distribution assets in a deregulated environment, more substation monitoring and control automation is now necessary. Automated monitoring and control has a dual purpose:

- Operate the power networks at the highest reliability levels economically possible.
- Keep pace with the tremendous volume of free-market energy transactions.

However, the increased amount of data generated by the new monitoring and automation systems has limited value if it is not processed correctly into usable knowledge. Today, in most cases, large amounts of raw data can easily inundate control room operators, which hinders rather than aids the reliable operation of the system.

This project demonstrated, under realistic conditions, the feasibility and potential benefits of intelligent alarm analysis and voice recognition technologies as means of alleviating this problem.

The project objectives were to:

- Complete the initial stage of development of an intelligent alarm analysis and diagnostics system to automatically classify and filter the thousands of pieces of information and alarms generated during an abnormal event on the grid, such as a regional blackout caused by a fault. The scope was limited to investigating the feasibility of the Alarm Analyzer tool.

- Implement voice recognition technology and evaluate its benefits in the entry of data and commands into a computer or other device in control rooms and other applications. Determine user acceptance of current voice recognition technology and estimate timesavings using voice recognition for selected work tasks.

1.3 Purpose and Organization of This Report

This report documents the evaluation of the feasibility and benefits of alarm analysis technologies and makes the information available to those undertaking similar studies in the future.

The report is organized into the following sections: Introduction; Technical Approach; and Conclusions and Recommendations. The Technical Approach section covers the concept development, installation and testing, and demonstrations of the Alarm Analyzer tool and voice recognition technologies.

1.4 Technical Concepts of the Proposed Solutions

The concepts behind the proposed technologies are straightforward, but their implementation is highly complex. It has required many years of development by the most advanced research centers in the respective fields. Fortunately, the timing of this project, in terms of the development status of the technologies, and the integration of the appropriate components and the applications, was excellent.

The cost of the required hardware and software has dramatically decreased, to the point where their commercial use has become attractive. The issues remaining dealt mostly with the costs and consequences of their adaptation to particular applications. For example, the effort of interfacing the new hardware and software with existing hardware and software, the ease of use, and the value derived from their application had to be determined.

The concept of the Alarm Analyzer is centered on having a knowledge base (reference) of the normal and abnormal states of the system, receiving real-time information on the sequence of events occurring for various contingencies, and comparing the new information against the reference. For control room operators, this means filtering nuisance, sympathetic, and irrelevant alarms, processing the relevant information; prioritizing it; displaying the root cause of the event (type of fault), where it is located (component involved), and recommended action (future version of Alarm Analyzer).

Communications and computational technologies have matured sufficiently to perform all steps in less than a minute for large control areas involving several hundred buses. They are also now affordable. Given the necessary field inputs, the desired analyzer functions at this stage can be performed by rule- and simple-logic-based decision programs.

Voice recognition, on the other hand, requires highly complex algorithms to allow rapid and highly accurate interpretation and conversion of speech spoken by any speaker. Sophisticated pattern recognition techniques are employed. Within the last four years, great breakthroughs have been achieved and today’s commercially available software can recognize more than 120,000 words in context, dictation is continuous, and training and enrollment takes less than three hours. The programs cost less than $200 and can be run successfully on the lowest end Pentiums, opening up many applications for voice recognition.

1.5 Commercialization Potential

The limited economic information obtained while performing this feasibility project and previous experience working in the utility industry have led to the following observations regarding the Alarm Analyzer and Voice Recognition technologies:

- The Alarm Analyzer promises to be a tool urgently needed not only by control room operators in the utilities, but by the new generation and transmission system operators, such as California Independent System Operators (CALISO), and large customer-owned power facilities (such as refineries).
- The concept of the Alarm Analyzer can be scaled down and applied in industrial plants and processes.
- The need for Alarm Analyzers in the electric power industry will continue to grow as utilities merge and become more interconnected and power exchange transactions increase in number, with direct access down to the residential customer-level nationwide.
- The expected cost of an Alarm Analyzer will vary widely depending on the complexity of the power grid on which it is being applied. To reduce the cost, the commercial version of the Alarm Analyzer must be designed for simple initial programming and for automatic self-reprogramming to accommodate changes.
- In the case of voice recognition technology, applications that involve large blocks of text result in the highest productivity gains. However, jobs where the operator has to both use their hands and eyes while making notes or entering data are ideal candidates for voice tools. Although the time to complete the job may be reduced only slightly, the quality and accuracy of the job can improve significantly, because multitasking is significantly enhanced with voice data entry and voice computer navigation.
- To create a market for voice recognition products, it is necessary to educate potential customers and thus gain wider acceptance for the technology.

1.6 Benefits to California

The benefits expected for the State of California from the application of the technologies proposed in this project can be categorized as follows:

- Higher power delivery system reliability translates directly into a better quality of life. This becomes most noticeable in the event of a power outage, when loss of life and economic losses are highly probable.
- Improved reliability also produces economic savings. Power disruptions can result in millions of dollars in losses when large areas and several hours are involved. The Alarm Analyzer can directly alleviate this problem. Since voice recognition has been shown to improve work productivity, it also yields potential economic benefits.
- For any electric utility user to enjoy the benefits of direct access, all must have the capability to access any available low-cost energy resource at any time. For this to

happen, it is necessary to have a stable and robust system. The Alarm Analyzer and voice recognition technologies both contribute to this end.

- Environmental benefits are derived from improved reliability and from the capability to access distant and diverse energy sources. On a reliable system, less generation and transmission lines need to be built, and if they must be built, they can be located where there is minimal impact on the environment.

2.0 Technical Approach

2.1 Alarm Analyzer Task

2.1.1 Concept Development and Prototype Design

The project used status and measurement information and time-tagged event information, obtained from Asea Brown Boven (ABB) relays, to determine the existence of conditions that should be alarmed to the operator, as well as conditions of predictable alarms that should be filtered prior to presentation to the operator. This is the initial phase of a more sophisticated smart alarming project.

The goal and scope of this first phase was limited to the implementation of logic within the substation to identify a small, selected set of conditions that should be treated and alarmed (or ignored) differently than is done with conventional supervisory control and data acquisition (SCADA) technology. Appendix I, *Preliminary Requirements Summary*, provides further details on the prototype specification and work plan.

Initially, Test Laboratories Inc. (TLI) supplied the equipment needed to implement a prototype. However, their proposed design concepts were not compatible with SCE's present or future installations. This was verified on a field inspection to Houston Lighting and Power where TLI had conducted a similar project. As a result, SCE selected an alternate supplier, Hathaway Industrial Automation (HIA).

HIA provided a Substation Information Server (SIS) unit and a configuration and Human Machine Interface (HMI) workstation, both installed to simulate the Dalton substation. In addition to providing the hardware, HIA implemented local logic to perform the fault/event detection logic based on data obtained from ABB relays. The SIS unit was attached to the substation Ethernet LAN and used Modbus+ communications to receive data from the ABB relays. The data had to be sufficient, in both type and nature, to permit the logical computations required to detect the specific set of conditions selected for the first phase of testing.

SCE and HIA defined the test scenarios and the data required for implementation. Implementation included the creation of simulation screens to permit the manipulation of the test scenario data so that the logic in the SIS could be tested without requiring that the ABB relays to detect an actual fault.

HIA provided training to SCE personnel in the use of the configuration and application development tools of the SIS and the workstation. The workstation was supplied with a full set of such tools and HMI applications including a custom graphic display builder, a trending package, an alarming package, a report generator, and a historian.

At the conceptualization stage SCE and HMI made the following key assumptions, which the prototype tests validated:

- It is possible to obtain the data from the ABB relays necessary for making the logical decisions within the SIS in a timely manner.
- The scenarios selected can be accurately and thoroughly defined and detailed

- Testing of the logic can be done through some means of creating the specified scenarios using the ABB relays.

2.1.2 Installation and Testing

2.1.2.1 Introduction

The purpose of the tests was to verify that the Alarm Analyzer supplied by HIA met SCE's requirements for smart substation alarming. Testing also presented an opportunity to train SCE personnel through active participation in the project. The terms listed below are used to describe system components and the testing and simulation equipment used in the test:

- **Workstation**. This term indicates the UNIX equipment used for the HMI, for configuration of the system, and as an X-server.
- **SIS**. This term indicates the Pentium computer that provided communications to the relays and RTUs.

Except where noted, tests were designed to run in the sequence given here. The proper sequencing of tests was necessary because of setup procedures that may have been necessary in previous tests. However, circumstances often required that the sequence be interrupted. Such interruption or rescheduling required the agreement of SCE and HIA so that the impact of the sequence interruption would be recognized.

Successful testing usually involves the active participation and understanding of test procedures by both parties, but to expedite matters, it was primarily HIA personnel who executed the tests. This provided SCE with the opportunity to observe and question the test results. Upon successful completion of each section, the test supervisors signed off that section as complete and accepted.

The test period began with an orientation meeting for all personnel involved in the testing. The purpose was to review the test procedures and to establish what was to be accomplished by the end of the test period. The test period concluded with a review meeting. If unsatisfactory test results were obtained, this meeting would determine the proper course of action needed to obtain satisfactory results. Each day of the test period began with a brief meeting to establish the day's test plan and closed with a brief meeting to review and prioritize any pending discrepancy reports.

The first step in the testing procedure was to inspect the hardware shipment for completeness and quality. The system test configuration was verified by a walk-through inspection. During this walk-through, all test personnel became familiar with the overall configuration. Table 1 shows the additional test equipment used for the simulation.

Table 1. Additional Test Equipment

Description	Supplier
PLC and PLC program to simulate relay global data	HIA and others
TPU 2000R and DPU 2000R Relays	SCE

2.1.2.2 Start-Up and Initialization Procedure

System start-up and initialization was an automatic process requiring no user intervention beyond applying power to the individual components. The Sun system was configured to start the necessary DAS4000 programs. SIS was configured to automatically load from the Sun workstation. This portion of the test covered the proper startup and shutdown procedures for the DAS4000 system.

1. Start with the Sun workstation and its peripherals turned off.
2. Use the power switch to apply power to all of the workstation's external devices.
3. Use the power switch to apply power to the CRT display monitors.
4. Use the power switch to apply power to the Sun workstation processor. After a brief interval, the Sun workstation processor will automatically run its power-up diagnostics, its start-up script, and finally prompt for login.
5. Logon to the system using "TIS4000" for user name and password. The window environment will start up with the applicable windows for the station being started.

2.1.2.3 Restart Procedure

This procedure was also demonstrated.

1. Apply power to the SIS. The communication link is initiated automatically.
2. Verify that the system is up and functioning correctly.
3. Prior to powering down the Sun computer, disable the DAS4000 software. To do so, log on as root with the password tissystem, change to the TIS4000/tasks directory (cd/export/home/tis4000/tasks), and stop the DAS4000 software (stop_TIS). Type "init 5" to halt the Sun's operating system and shut down the Sun computer. The CRT display monitor should be turned off first and external devices last.
4. Turn off the SIS.
5. Repeat the power-up and initialization sequence described above, and restore the system to full operation on the network.
6. Log on to the system and verify that all communication functionality has resumed.

At the completion of this test, it was expected that all system equipment be powered up and connected.

2.1.2.4 Acceptance

Following the procedures described above, the system had to be taken to a fully inoperable and powered-down state and then restored to full functioning. The test was considered acceptable if system function was fully restored after completion of the procedures. If additional steps were required, the test document had to be amended to include and properly document these additional steps.

2.1.2.5 Smart Alarming

This section of the test procedure verified the ability of the DAS400 to properly filter alarms based on the scenarios provided by SCE for this project. The intent of this demonstration was to show the feasibility of automatic alarm analysis for substation control rooms. The objective was to filter irrelevant and sympathetic alarms, and present to the operator a very brief message stating what event took place, where, and a list of only those alarms that were relevant to his purposes.

- **Scenario 1 – Extended Delay**. If the following signals change from normal to alarm, wait 5 seconds to alarm: Relay AC Potential Fail, RH Liquid HLI, RH Liquid PW Fail, RH L. Ellen HLI, RH L. Ellen PW Fail, Azusa Citrus HLI, and Azusa Citrus PW Fail.

  Procedure:

  1. Display the graphic for Scenario 1 on the CRT. Ensure that the system is updating the display.
  2. Using the PLC program to simulate values from the relays, change the state on the first signal. Signal should stay in the alarm state for five seconds before the alarm is heard.
  3. Using the PLC program, change the state of the point back to normal and clear the alarm.
  4. Using the PLC program to simulate values from the relays change the state of the first signal again, but this time change it back to normal before 5 seconds have elapsed. Verify that the value changed on the display but no alarm was sounded or recorded in the alarm log.
  5. Repeat steps 2 through 4 for all the remaining test points.

- **Scenario 2 – 12 kV Bus Tie CB Trip**. If the 12 kV Bus Tie goes from closed to open, inhibit the following alarms: Relay AC Potential Fail, RH Liquid HLI, RH Liquid PW Fail, RH L. Ellen HLI, RH L. Ellen PW Fail, Azusa Citrus HLI, and Azusa Citrus PW Fail.

  Procedure:

  1. Display the graphic for Scenario 2 on the CRT. Ensure that the system is updating the display.
  2. Using the PLC program to simulate a 12 kV Bus Tie changing from closed to open and all of the signals above go from normal to alarm.
  3. Verify that the alarm for the 12 kV Bus Tie is displayed, the alarm is sounded, and that none of the other signals were alarmed.

- **Scenario 3 – 12 kV Line CB Trip**. If any of the 12 kV Line CBs (Bender, Jarvis, Damerel, Gravel, Von, Lager, Concrete, Winark) go from closed to open, inhibit the following alarms: Relay AC Potential Fail, RH Liquid HLI, RH Liquid PW Fail, RH L. Ellen HLI, RH L. Ellen PW Fail, Azusa Citrus HLI, and Azusa Citrus PW Fail.

  Procedure:

  1. Display the graphic for Scenario 3 on the CRT. Ensure that the system is updating the display.

2. Using the PLC program to simulate one of the 12 kV Line CBs changing from closed to open and all of the signals above go from normal to alarm.
3. Verify that the alarm for the selected 12 kV Line CB is displayed and is sounded, and that none of the other signals were alarmed.
4. Clear the alarms.
5. Repeat steps 2 through 4 for all of the remaining Line CBs and in any combination desired.

2.1.2.6 System Utilities

The purpose of this test was to demonstrate the system utilities that are included with the system, such as database creation, display creation, and alarm configuration. The testing also included demonstration of the on-line configuration tools.

The standard DAS/4000 utilities demonstrated in this test included:

- DataVu
- AlarmVu
- DisplayVu (edd/dm).

Procedure. From the workstation, run the listed utilities and demonstrate the features and functions of each. Create actual database blocks, download them to the SIS, and create displays to view them and add them to the alarm manager and displays.

2.1.2.7 Y2K Readiness Check

The test demonstrated the system's capability to properly handle the date transition from 1999 to 2000 without manual intervention, and to show that, as a whole, the system would not be adversely affected by the migration of the year representation from the 1900s into the 2000s. The test showed that the system continued to function normally, and that no data was lost or miscalculated, prior to, during, and after the transition from 12/31/1999 to 1/1/2000.

- **Procedure**. Set the system clock in the workstation set to December 31, 1999 at 23:30 hours. Allow the system to run and simulate points changing status. At 00:30 hours on January 1, 2000, collected data will be displayed along with the recorded alarms to show the system remained functioning. Retrieve information from the system and review it to verify its correctness.
- **Acceptance**. The system's functions will not be impacted by the year rollover and no data will be lost or incorrectly computed due to the rollover. If no collected information is lost, misfiled, or miscalculated, and the system continues to function properly, the test will be considered successfully completed.

2.1.3 Test Results

The Alarm Analyzer demonstration was performed using the same substation information server that would be used on-line. This equipment interacted with signals and components identical to those installed at Dalton Substation, the test case substation for this part of the

Project. Working off-line with a controlled set-up allowed many different scenarios to be simulated and triggered at will to generate the required data and complete the development effort within a reasonable schedule and budget.

Feasibility of the Alarm Analyzer concept was demonstrated successfully off-line for the Dalton 66/12 kV Substation using two actual scenarios and the same type of communication and device signals available at the substation.

A bus tie circuit breaker trip and a feeder circuit breaker trip were simulated. The Alarm Analyzer was able to accurately detect, locate, and identify the disturbance in both scenarios. With the Alarm Analyzer in use, the alarms generated were filtered and reduced in number from seven to one in Scenarios 1, 2, and 3. The simplified and prioritized information was displayed on a screen showing the same one-line diagram of the substation used by the control room operators overseeing Dalton Substation. The screen was animated with blinking color-coded messages (differentiating between minor- and major-class alarms) and sound to alert the operator to the failed components. It was observed that through use of the Alarm Analyzer, the time required to produce an accurate diagnostic of an event could be reduced from several hours or days to less than 2 minutes.

The main hardware selected to build the Alarm Analyzer system was the HIA DAS 4000 substation information server (SIS) and a Sun Workstation. The SIS contains the necessary protocols to interface with the relays and other monitoring devices with minimum customization. The SIS also has enough computational capacity in its calculator to process the analyzer's logic program. The programming required is relatively simple and can be learned in a few hours by a person with average programming skills. However, the vast number of possibilities for different scenarios make it necessary to first develop more sophisticated logic that would allow the logical combination of basic building blocks to create the correct variations of scenarios in response to the protection device signals collected.

In view of the clear and positive results achieved and the large potential impact of the Alarm Analyzer, a continuation of this work in the form of a pilot project at a typical regional control center is strongly recommended. The intelligent alarm analyzer's information regarding the type and location of the disturbance would be combined with an outage estimator system to generate an alert and inform the affected customers of the expected outage duration time.

2.2 Voice Recognition Task

2.2.1 Concept Development, Prototype Design, Installations, and Testing

Development was focused primarily on optimizing performance of existing computer hardware by using the speech recognition functionality currently available with ViaVoice 98 Executive software. Recent advances in continuous speech recognition, program navigation, and related new equipment promise significant benefits in reducing the man-hours and reliability of reports generated by substation and transmission field crews. For office documents generated using a PC, voice recognition has proven to be a significant time saver and offers an alternative to physical fatigue of both the eyes and hands. The objective of this effort was to determine user acceptance of current recognition technology and to estimate timesavings using voice recognition for selected work tasks.

The hardware used for this study was a Dell Inspiron 233 MHz. notebook computer with Windows 95 operating system. Substation work utilized a desktop 233 MHz Dell computer with Windows 95 using the SCE network and multimedia hardware. The development effort, described below, is subdivided into three distinct application areas:

- Substation Applications
- Transmission Field Crew Applications
- Office Applications.

2.2.1.1 Substation Applications

Concept Development. Demonstrations were scheduled for two SCE substations, Lighthipe and Moorpark. Following each demonstration, the responses of supervisory personnel and staff were evaluated to determine the utility of using voice recognition to complement existing reporting methods

Prototype Design. A Visual Basic program using the Multiple Document Interface (MDI) feature of Visual Basic was developed. This program, called Multi-Notes, allows multiple document windows for on-line real-time voice reporting and may be operated in conjunction with ViaVoice 98. The Save command of Multi-Notes allows all files to be concurrently saved to disk with a single command. The intent of this program was to replace the pencil and paper scratch pad notes with voice-entered notes and to transfer selected notes, through the copy and paste functions, into TaskMaster 4.0. For the majority of work at substations, it was found that direct voice entry into TaskMaster 4.0 was preferable to using Multi-Notes. Demonstrations involving Multi-Notes were deemed not to provide significant timesavings, except during peak workload intervals. Therefore, attention was focused on direct voice dictation into TaskMaster 4.0, as it was believed this would provide more immediate user benefits.

Installation. ViaVoice 98 Executive, version 5.3.1.30, was installed at Lighthipe along with the Voice Mouse software. TaskMaster 4.0 was installed by SCE personnel and connected to the Lighthipe network. A customized 500-word dictation vocabulary was installed that included locations, cities, names of SCE personnel and abbreviations. Customized dictation and navigation macros were created and installed.

Testing. The Voice Connexion staff performed the testing.

2.2.1.2 Transmission Field Crew Applications

Concept Development. A demonstration of ViaVoice was scheduled at SCE's Compton Metropolitan Transmission office. Initially, the plan was to use a digital recorder to accumulate field data related to the Patrolman's Log (line inspection report required by the California Independent System Operator) and transcribe this information using special Olympus-provided ViaVoice software. Since field crew personnel are provided with a Dell notebook computer for use in their trucks, the initial plan was modified to install ViaVoice directly on the notebook and avoid special transcription hardware and software. Following the demonstration, the field crew supervisor and staff members realized ViaVoice could potentially enhance the existing Patrolmen's Log data entry.

Prototype Design. An SCE Dell notebook computer was configured with an Olympus Personal Computer Memory Card International Association (PCMCIA) card, D-1000 digital recorder and Olympus ViaVoice software was installed prior to the Compton demonstration. At the time of installation, the Olympus dictation software used ViaVoice Gold rather than ViaVoice 98 Executive.

Installation. ViaVoice 98 Executive, Version 5.3.1.30, was installed on a field crew's Dell notebook computer. A field crew staff member was trained on ViaVoice and a customized vocabulary was also created and installed. The vocabulary contained names of eight individual patrolmen and 398 66 kilovolt (kV) line names.

Testing. A patrolman was trained in the customized vocabulary and became familiar with the use of the ViaVoice software. The patrolman experimented with voice dictation while working on the Patrolman's Log.

2.2.1.3 Office Applications

Concept Development. A demonstration of ViaVoice was scheduled at SCE's Rosemead facility for the Manager of Environmental Research, who has limited hand mobility due to a spinal injury. This managerial position requires extensive document creation using Microsoft Office. Following the initial demonstration, the manager expressed interest in having the voice dictation system installed on his computer and applying its functionality to his work tasks.

Prototype Design. The standard ViaVoice system operates with a headset directly wired to the PC multimedia sound card. The manager noted that the wiring restricted his office mobility because it became caught on the arm of the wheelchair. To eliminate the problem, wireless low-cost office microphones were reviewed and selected. Wireless RF headset microphones from Shure Brothers, LightSpeed, Telex and EmKay were review for the office application area. The EmKay was selected because it combines a lightweight headset in a single unit with a transceiver, provides excellent acoustic background rejection, and is easily maintained. The unit is provided with a secondary battery pack mounted to a base unit that readily detaches for insertion into the headset.

Installation. ViaVoice 98 Executive, Version 5.3.1.30, with Voice Mouse software was installed onto the Dell desktop computer. The EmKay wireless microphone, #RF-3296, was installed, tested, and adjusted to operate with computer and associated voice recognition software. The Voice Connexion staff provided voice enrollment and training for ViaVoice.

Testing. Practice and testing was performed using SpeakPad and MS Word 97. In the case of this user, recognition with the wireless was observed to be excellent.

2.2.2 Test Procedures

2.2.2.1 Substations

We created a script modeled on actual TaskMaster reports. The script contained two Clearance Reports, two Main Log Entry Reports, one 220 kV Interrupt Report, one System Status and one A.M. Report. This script was used to measure and compare keyboard data entry with that of voice.

2.2.2.2 Transmission Field Crews

To compare keyboard versus voice, three fields of the Patrol Log were selected for testing. The three log fields selected for comparison testing were Location (site of investigation), Description, and Comments. The sentences used for comparison are listed below:

- **Location**. Just South of Los Alamitos Steam.
- **Description**. A hawk got into the bottom phase and flashed over the post-type insulator.
- **Comments**. The repair to the insulator will have to be completed on a different day.

Additionally, live dictation in the truck was performed in the field using the Patrolman's Log.

2.2.2.3 Office

Dictation was performed using the desktop computer and the wireless microphone.

2.2.3 Test Results

2.2.3.1 Substation

Testing was performed by Voice Connexion at Lighthipe using the Dell desktop computer operating directly into TaskMaster 4.0. The results of the multiple reports with dictation of 225 words into seven reports yielded the following comparison:

- Voice = 7.5 minutes Keyboard/Typing = 15 minutes
- Voice Rate = 30 words/minute Typing Rate = 15 words/minute.

The above results are not representative of normal dictation rates, typically 120 to 180 words per minute. Nevertheless, voice rate is twice that of a typical male, non-secretarial, touch typist. The low dictation rate is due to several factors. For each of the seven reports, only a few words are dictated into many of the various fields, extensive movement between fields is required, considerable delay is due to accessing each of the seven reports (even with navigation macros). The 233 MHz. Dell machine, although acceptable for use with ViaVoice, could benefit significantly with a commercially available 450 or 500 MHz machine. Some degradation of response time was observed to be associated with Novell network delays.

2.2.3.2 Transmission Field Crew

Using the above-cited test procedure of the transmission field crew, the above test results were obtained.

- Keyboard Entry. = 129 seconds (approximately 2 minutes)
- Voice Entry. = .17 seconds plus about 5 seconds for editing.

In the field, after adjusting the microphone gain of the notebook computer for truck noise, voice recognition dictation operated satisfactorily when operated in conjunction with the Patrolman's Log. It was suggested that a microphone with an ON/OFF switch would enhance performance.

2.2.3.3 Office

Voice dictation using the EmKay wireless microphone in a relatively noisy office cubicle was found to be excellent. The dictation performed was rapid, natural, accurate and integrated well with typical office work tasks.

2.2.4 Demonstrations

To evaluate the voice recognition technology, demonstrations were performed at sites where the users themselves would apply these tools. This was important because real-world conditions, such as ambient noise interference on the headset microphones, use of specialized vocabulary by the operators, and computer literacy of the personnel, had to be accounted for in the assessment. In this project, field personnel's feedback was the most important data to be obtained.

This Task was performed at four different sites involving three different applications as follows:

2.2.4.1 Substations:

- Lighthipe **Substation**. The first demonstration was performed at Lighthipe Substation, a Regional Control Center with jurisdiction and control over more than thirty substations. Four operators are present during the day shift. The earlier releases of IBM's Via Voice software had been previously evaluated at Lighthipe. The substation's personnel at that time requested an electronic version of their paper scratch pads. These pads are sheets of paper divided into cells used by the operators to write their notes during extra busy periods and later used to fill out reports. With the electronic pad developed in this project the operator creates as many cells as needed, titles each cell according to her needs, and can dictate directly to each. Later she can quickly edit, cut, and paste the information to the proper report forms.
- Management at Lighthipe Substation requested the development of four frequently used reporting forms to input text directly by voice. Since these reports are used frequently, the benefit of voice input would be available not only during the peak activity moments but also throughout the day. A shell program called TaskMaster manages these reports and many other documents used at the control consoles. The challenge was interfacing the voice recognition with TaskMaster. This was accomplished in spite of several changes due to a major upgrade to TaskMaster. The four reports can be completed via voice in less than half the time needed to complete them using the keyboard and mouse by a touch typist. The accuracy achieved was 97 percent and improved with increased use of the program because of the recognition capabilities of the software. Higher productivity can be obtained when dictating documents with larger amounts of text. The reports are usually one page long and have only a blank or a few lines to fill in at a time. The operators noted that the brief sections of text they use and the lack of experience with dictation made voice input seem awkward, although it was still faster than typing in the information.
- **Moorpark Substation**. The use of the electronic scratch pad (MultiNotes) and the four reports were demonstrated at a second regional control center at Moorpark Substation.

This permitted a more thorough test of the software's compatibility, which caused the weaknesses to surface. At Moorpark a connection to the server which hosts TaskMaster could not be established and the backup copy residing on the demo PC had to be used. This created some erratic responses when inputting the same type of information, which had no problems at Lighthipe. Navigation via voice also had certain glitches not observed previously. These problems are attributed to different TaskMaster versions and to the lack of robustness in Via Voice to handle these changes.

2.2.4.2 Field Transmission Crew

- A different application involved a transmission line patrolman who inspects the overhead lines and structures as he drives by the installations. This is an inspection mandated by the California Independent System Operator and a one-page form with the patrolman's comments is required. The inspectors have to stop their vehicle to write or wait until they are back at their desk. In either case the procedure is not efficient and is prone to error, as it depends on the inspector's memory. With voice input, the time required to enter all the information on the form was approximately three times faster than by hand and the accuracy was practically 100 percent after re-calibrating the headset's microphone to account for the vehicle's and road noise. This application showed that voice input frees the person's hands and eyes and enhances multitasking, in this case contributing to improved system reliability and safety. Initially, a digital recorder was to be used to dictate in the field and then the information was to be downloaded to a PC in the office. But the patrolman carried a laptop and dictation was done directly into the laptop. The compatibility errors observed at Moorpark were not present here due to an improved interface between the voice and TaskMaster software loaded on the PC. The patrolman and his supervisor commented that their report comments are too short to consider changing to voice input only.

2.2.4.3 Office

- The last demonstration was an office application for a manager with limited hand and arm mobility who was confined to a wheelchair. This person, who had experience with other voice recognition systems, reported that this system was easy to use as well as accurate. He experienced a problem with the headset's cord, which would tangle on the wheelchair. The standard headset was replaced with a wireless headset, with excellent results. Another minor problem was a conflict with an existing application, which had to be closed when using Via Voice. The user commented that his productivity improved when using voice input on long documents but was not worth setting up for brief text like e-mail messages. He also observed that a cubicle environment is not conducive to dictation because of the distraction from and to neighbors. He also felt self-conscious dictating in an environment with no privacy. A voice-activated mouse was tested with good results in terms of accuracy, which could greatly benefit those people prone to carpal tunnel syndrome or who are physically impaired.

Voice data input has been demonstrated to have a strong potential to improve productivity and accuracy. In the cases of the control room operators and the patrolman this would contribute to improved reliability at substations and lines. The technology is ready for system-wide use, but the applications have to be judiciously selected to obtain its full benefits, and it has to be implemented with care to avoid interface problems.

The above-outlined demonstrations enabled comparisons between existing methods and the proposed technologies. These comparisons made evident the impact on reliability of applying these technologies because accuracy and speed of response were considered. Although it was too early in the development process to establish exact costs and benefit values, the governing parameters could be identified. Preliminary indications of the relative merits and competitiveness of the technologies could be deduced and used to determine further efforts.

3.0 Conclusions and Recommendations

3.1 Project Objectives

The project objectives were to:

- Complete the initial stage of development of an intelligent alarm analysis and diagnostics system to automatically classify and filter the thousands of pieces of information and alarms generated during an abnormal event on the grid, such as a regional blackout caused by a fault. The scope was limited to investigating the feasibility of the Alarm Analyzer tool.
- Implement voice recognition technology and evaluate its benefits in the entry of data and commands into a computer or other device in control rooms and other applications.

3.2 Project Outcomes

The objectives were met by developing the Alarm Analyzer tool, implementing voice recognition technology, and conducting successful demonstrations of each.

Project findings were:

- Use of the Alarm Analyzer tool reduced the time required to produce an accurate diagnostic of an event from several hours or days to less than 2 minutes. These results are based on simulations of actual events occurring at the Dalton Substation.
- The voice recognition tools evaluated in this project resulted in a productivity increase of at least 200 percent in entering information into a computer file, with an accuracy rate greater than 97 percent. These results are based on a comparison between keyboard entry methods and voice input.

3.3 Actual Findings

In all areas reviewed in this study, substations, transmission field crew, and office personnel, manpower and timesavings were observed. Cost savings are directly related to the amount of time spent performing manual keyboard text entry or speech-to-text entry. Therefore, maximum benefits accrue where large amounts of text are entered.

The text entry work tasks for the application areas reviewed vary widely. For this reason, economic saving using voice versus manual input is difficult to estimate unless it is directly related to specific SCE application areas. Nevertheless, this section of this report details what appears to be a reasonable typical savings with the use of voice recognition.

Complementing existing SCE computer systems with ViaVoice 98 Executive software requires a minimal cost per user (less than $150 in single unit quantities). Additional peripherals related to application needs, such as RF voice I/O, telephone and computer access, or custom array noise canceling microphone, increase per user cost.

Software installation and voice enrollment by individual users requires approximately 2 man-hours. Use of voice with application software and recognition corrections and customization are estimated to require an additional 4 to 6 hours. Support customization and individual training service of 4 hours typically incur an additional cost of $500.

Installation, training, and system optimization are estimated to require 8 hours per user with an estimated hourly rate of $20. This yields:

Software Cost	=	$150
Training Services	=	$500
SCE Manpower Cost	=	$160 per user
Total	=	$810

To estimate the cost savings, a man-year is assumed to be 2,000 hours. If, in general, 10 percent of these hours are used in reporting, this yields 200 hours per year for documentation. At the above rate of $20 per hour, this cost would be $4,000. Since voice should save at least 40 percent of this reporting time, only 120 work hours would be needed when using voice. Using these assumptions, this yields a saving of 80 hours per year times $20 = $1,600 per person per year. Note that the payback period for the initial investment is approximately 6 months to recover the $810 expenditure. This is considered a conservative estimate, since e-mail and other correspondence will also benefit from voice dictation, in addition to report documentation.

Entering data into Taskmaster 4.0 and the Patrolmen's Log requires the operator to view the computer screen to input information into each specific field and move between fields. Speech dictation into Microsoft Word or the ViaVoice Speak Pad does not require constant viewing of the screen. For this reason, database field dictation is more taxing and slower than normal continuous dictation speaking rates. An interactive field prompting, with recognition verification of the spoken field would greatly enhance the user friendliness of database real-time information capture systems. Currently, general-purpose large vocabulary continuous speech systems do not afford this degree of man-machine interaction. The need for this technology exists in many areas besides the needs of SCE, i.e., warehousing, distribution, inspection, inventory, paperless picking. Recent handheld microprocessor developments and current recognition technology properly combined now allow this type of application functionality to be achieved.

3.4 Conclusions

- Voice data input has strong potential to improve productivity and accuracy. For control room operators and the patrolman, this could contribute to improved reliability at substations and lines.
- While the technology is ready for system-wide use, applications have to be judiciously selected, and implemented with care to avoid interface problems.

3.5 Recommendations

Suggested improvements to be implemented in the various applications are provided below.

3.5.1 Substations

The reporting with TaskMaster 4.0 and ViaVoice would be substantially more efficient if the Dell machines were upgraded from 233 MHz to 450 to 500 MHz.

When Microsoft Word is upgraded to Word 97 (version 8), ViaVoice features can be more completely used and TaskMaster 4.0 can be more closely integrated with voice.

Inspection of substation equipment and inventory control can be accomplished using the stand-alone MicroIntroVoice II or alternately with the new DS-150 digital recorder and with ViaVoice 98 Executive.

3.5.2 Transmission Field Crews

A more hands-free and remote method for voice input to the notebook computer is better suited to this application than direct headset wiring to the notebook.

Wireless operation at a distance of 20 to 30 feet is now available with the EmKay headset (RF-3296). This unit provides excellent recognition, even in a fairly noisy environment, and does not require the user to be tethered to the notebook computer. The unit is provided with a headset mute switch. This allows the operator to terminate the headset audio pickup when recognition is not desired or for the voice system to ignore other radio conversations.

While the inspector is in the truck and entering data into the Patrolman's Log, two additional new microphones should be considered: the Andrea AutoArray hands-free automotive microphone and the ANC-300 hand-held computer microphone.

3.5.3 Office

The greatest gains in productivity for using voice recognition are where a large portion of a person' time is spent generating a text document. Entry into structured database reports is slow relative to standard word processing speeds. Dictation into a word processor actually can be done at a rate of 120 to 180 wpm versus 60-80 wpm for a skilled typist.

Fatigue and hand or eye damage can occur due to repetitive muscle use. Voice dictation does not require the eyes to view the computer screen, except to edit generated text, thereby reducing eyestrain. For prevention of carpal tunnel symptoms or for people with carpal tunnel, voice is highly recommended as an alternate or supplemental technology for text generation.

Where noisy office cubicles interfere with voice recognition, the EmKay wireless or a similar product should be used instead of the standard headset microphone.

Phillips' new SpeechMike device provides an all-in-one handheld microphone, with loudspeaker, mouse trackball and programmable buttons designed to be used with voice recognition software products such as ViaVoice and Voice Connexions SpeechRecorder. This unit is ideal for executives and legal staff.

These factors, as well as aid to the disabled, establish a clear need for further service efforts directed toward office work at a utility's facilities.

3.6 Summary

In summation, Alarm Analyzer and voice recognition technologies have proven to promote substation reliability by filtering alarms for the operators, thus avoiding information overload. In view of the successful demonstration of the Alarm Analyzer, a continuation of this work in the form of a pilot project at a typical regional control center is highly recommended. Voice recognition technologies also have the potential to improve productivity and accuracy by freeing hands and eyes to enable multi-tasking. In the case of the control room operators, this would also contribute to substation reliability. Although the technology is ready for system-wide use, applications should be judiciously selected for maximum benefit and implemented with care to avoid interface problems.

Appendix I
Intelligent Alarm Analyzer Project – Preliminary Requirements

Appendix I
Operational Theory for the ULTRA-NET^{TM} Satellite System

Purpose

This document provides a functional description of the ULTRA-NET™ satellite communications system, focusing primarily on the system interfaces and system data flows. This document represents the present implementation of the system.

System Interfaces

Three separate data interfaces exist, one for supervisory control and data acquisition (SCADA) data operations, one for network management, and one for administrative functions.

The SCADA data is communicated to and from the SCADA master computer through an RS-232 interface. The interface card used at this time contains eight RS-232 connectors per card. The data stream going to and from the SCADA master computer is Control Data Corporation (CDC) Type II or DNP 3.0 protocol. This message structure is well defined in the protocol documents for each protocol. Multiple RS-232 connections are used to simulate more than one remote terminal unit (RTU) connected to the SCADA master. This is necessary because many of the older protocols will only allow a small number of points to be retrieved from any one RTU.

The network management interface is through an Ethernet twisted pair interface (10BaseT). Information is communicated over this interface using TCP/IP protocol encapsulating ASCII messages. These messages contain:

- Message sequence number
- Problem device identification number
- Urgency type code
- Type of failure message
- Satellite hub identification number
- Satellite hub site name
- Ultra small aperture satellite (USAT) site name

The message is received by the central network management system and parsed, and the proper person is notified of the problem.

A number of administrative functions are available at the console of the hub embedded computer. These functions are carried on simultaneously with SCADA functions, with SCADA function having priority. Typical administrative functions are:

- Download software to a USAT
- Download configuration to a USAT
- Edit configuration databases for the satellite hub
- Monitor satellite hub and USAT performance statistics
- Control RF power level for the satellite hub and USATs
- Set frequencies for the satellite hub and USATs
- Configure newly installed USAT in the satellite hub database
- Read and write USAT memory for software diagnostic purposes

Signal Descriptions

Both the outbound signal (satellite hub to the USAT) and the inbound signal (USAT to the satellite hub) are direct sequence spread spectrum with Binary Phase Shift Keying (BPSK) modulation. Forward Error Correction (FEC) at a rate of 1 bit per two bits in the original message is employed in both directions. Spread spectrum on the outbound channel provides high rain fade margins with a small receiving antenna at the USATs. The outbound channel consists of a single signal. The purpose of spread spectrum on the inbound channel is to reduce interference imposed on adjacent satellites when using a small antenna, provide high rain fade margins, and allow transmission by 50 USATs simultaneously.

Data Channel Overview

All operations on the system are done in one-second frames. Each outbound frame is divided into four packets. These packets can be either SCADA or network commands/data. The network commands/data are used for remote software downloads or modifying the configuration of the USATs. The satellite hub is capable of transmitting and receiving simultaneously (full duplex). The USATs are only capable of half-duplex operations. The satellite hub keeps track of the state of each USAT and only sends messages when the USAT is listening. The inbound message is made of the requested data plus some diagnostic information. Twenty-four words of diagnostic information are collected, with two words collected in each return frame.

Autonomous Polling Operation

The satellite system uses autonomous polling to collect data from the RTUs. In this method of operation, the USAT sends polling commands to its associated RTU. The response data is then placed in the memory of the USAT. The satellite hub polls the USAT and retrieves the RTU status stored there. The satellite hub stores this data in an internal database to be used to answer a poll request from the SCADA master. At SCE, the satellite hub polling rate is set so that no data in the satellite hub's database is any older than four seconds. If more than one packet is needed to retrieve data, several packets can be chained together to send the complete message.

To avoid delays in the execution of commands, any command received by the satellite hub is passed directly to the USAT on the next available frame. Special spread-spectrum codes are reserved to allow a quick confirmation of the command's execution at the USAT. Commands are executed in two to three seconds after receipt by the hub. With the present system design, up to seven commands can be issued from the satellite hub every second.

Additional Features

The present ULTRA-NET™ system has several additional features. A notebook computer can be attached to any USAT without interruption of the SCADA operations. This computer can be used for performance monitoring, installation aid, antenna alignment, and software download. A messaging mode is also available to allow "mail" to be sent back and forth between the USAT and the satellite hub. The status of any satellite hub may also be monitored remotely by connection of a computer to a dedicated USAT. All remotely accessible satellite hub functions are password protected to avoid unauthorized access. An additional feature that is a by-product of the spread spectrum system allows all USATs to be time synchronized to one another with a time tolerance of 0.2 misro-seconds.

Appendix II
Mod-2 USAT Test Report

Executive Summary

The ULTRA-NET™ system is a supervisory control and data acquisition (SCADA) system that monitors voltages, thermal limits, and tests for instabilities. The system is composed of remote terminal units (RTUs), ultra small antenna terminals (USATS), a satellite, regional hubs, and a SCADA Master. This system allows Southern California Edison (SCE) engineers to monitor remote substations quickly and cost effectively. It operates with a bit error rate (BER) of less than one error in 10-million bits (e.g. $1x10^{-7}$).

The BERs for the USAT Mod-2 data entries can conveniently be grouped into eight categories: zero errors, 1×10^{-10}, 1×10^{-9}, 1×10^{-8}, 1×10^{-7}, 1×10^{-6}, 1×10^{-5}, and 1×10^{-4}.

The proportion of in-specification vs. out-of-specification readings for the given sites was also analyzed. Out of a total of 7,999 entries, using the conservative BER specification (1×10^{-7}), 4,441 entries (56%) showed no errors, 2,267 entries (28%) showed errors that were within specification, and 1,291 entries (16%) showed errors that were out of specification. In summary, out of 7,999 data entries, 6,708 of the readings or 84% were within specification, while 1,291 or 16% were out of specification.

When the data are compared against the required SCE BER specification (1×10^{-6}), 4,441 entries (56%) showed no errors, 2,959 entries (37%) showed errors that were within specification, and 599 entries (7%) showed errors that were out of specification. In summary, out of 7,999 data entries, 7,400 or 93% of the data sets were within specification, while 599 or 7% of the data sets were out of specification.

For the 8/10/99 to 8/11/99 time period, using the conservative BER specification (1×10^{-7}), 10 out of a total of 207 units or 5% were determined to be out of specification. When the regular BER specification of 1×10^{-6} is used, this number drops to 3 or 1.5% of the units out of specification. Fifty percent of the units were tested at 0.6 kbps and fifty percent of the units were tested at 1.2 kbps.

This represents a dramatic improvement since the units' upgrade to the latest revision. Further improvements can be expected as more opertional time is accumulated. Improvements in production line testing and quality control have also contributed to the improved field performance.

Introduction

Because of the successful operation of this system, SCE is expanding the system and implementing improvements. One upgrade currently in progress phases out the Mod I USATs in favor of the more versatile Mod-2 version. The Mod-2 versions of the USATs have been installed at the Devers, Lugo, Mira Loma, Moorpark, and Rector sites. USAT performance data from these units was collected and the BERs from these data sheets were compared against the 1×10^{-7} BER specification for the October 1998 to July 1999 time period.

USAT Performance Data Sheet

The USAT performance data sheet provides such information as the hub terminal location, time/date of reading, USAT unit number, signal magnitude, signal to noise ratio, and the Receive and Round Trip BERs for the USAT communication link. The Round Trip BER reading includes both the Receive and Transmit BER, and will provide the data for this analysis.

It is important to note that the reported errors can sometimes be caused by a phenomenon other then a faulty unit. Errors can occur when a USAT is powered down without notifying the engineers recording the BERs, which results in erroneous error readings. These errors can be distinguished by looking at the Actual Error, denoted as Error,Acc in the USAT data legend, Errors, denoted as Errors in the Hub data legend, and the signal magnitude, denoted as Signal[pwr] in the USAT data legend. When the USAT Actual error and/or the Hub Errors are quite large and the signal magnitude is 0.0, one can assume that the USAT in question has been powered down, and that any errors resulting from this are erroneous.

The erroneous error readings were identified by bold type in the Excel spreadsheet entries, but were not included in the spreadsheet graphs. Furthermore, USAT unit numbers with entries containing missing data indicate that the particular unit was not installed yet. These incomplete entries were also removed from all plots and analysis.

Error Data

The Round Trip error data for Devers, Lugo, Mira Loma, Moorpark, and Rector were tabulated in Excel spreadsheets. Included in the spreadsheets were the USAT unit number, Receive BER, Round Trip BER, error specification (1×10^{-7}), unacceptable error indication, and the date and time the data were taken.

The USAT unit number is the SCE site number, Receive BER indicates the error at the USAT end from the RTU, the Round Trip error indicates the combined Receive and Transmit error from the Hub station, and the unacceptable error is a yes/no indication of whether the Receive error and/or the Round Trip error was greater than the error specification of 1×10^{-7}.

USAT Mod-2 Error Summary

From the recorded data, the number of out-of-specification USATs was determined. A unit was determined to be out of specification if its Round Trip error met or exceeded the error specification for 5% or more of the given time period. It should be noted that the 1×10^{-7} BER specification is a conservative error specification that the Technology Integration group of SCE uses for error analysis. The SCE BER specification that the ULTRA-NET™ system must meet is 1×10^{-6}, as set by SCE's Information Technology group. Both error specifications were used in this study.

For the 10/98 to 7/99 time period, using the conservative error specification (1×10^{-7}), 63 out of a total of 108 Mod-2 units were determined to be out of specification. When the official error specification of 1×10^{-6} is used, this number drops to 36. Moreover, the BERs for the USAT Mod-2 data entries can conveniently be grouped into 8 categories: zero errors, 1×10^{-10}, 1×10^{-9}, 1×10^{-8}, 1×10^{-7}, 1×10^{-6}, 1×10^{-5}, and 1×10^{-4}. Figure II-1 provides a bar graphs comparing Round Trip error magnitudes vs. frequency for the 10/98 to 7/99 period.

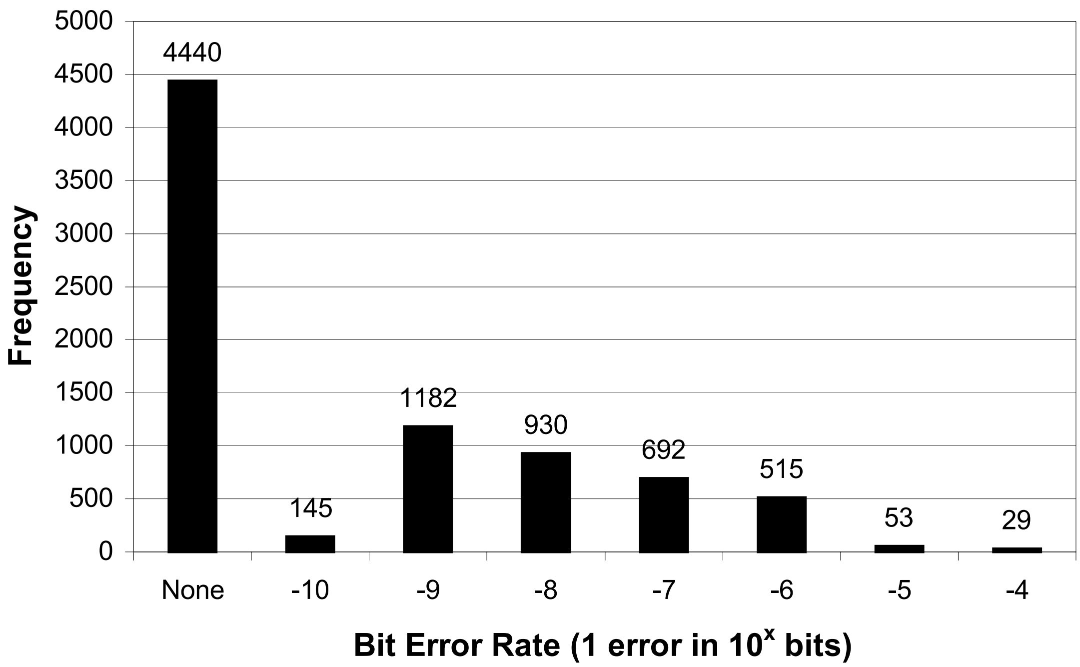

Figure II-1 - USAT Mod-2 Round Trip Bit Error Rate vs. Frequency for 10/98 to 7/99

The proportion of in-specification vs. out-of-specification readings for the given sites was also analyzed. Out of a total of 7,999 entries, using the conservative BER specification (1×10^{-7}), 4,441 entries (56%) showed no errors, 2,267 entries (28%) showed errors that were within specification, and 1,291 entries (16%) showed errors that were out of specification. In summary, out of 7,999 data entries, 6,708 of the readings or 84% were within specification, while 1,291 or 16% were out of specification.

When the data are compared against the required SCE BER specification (1×10^{-6}), 4,441 entries (56%) showed no errors, 2,959 entries (37%) showed errors that were within specification, and 599 entries (7%) showed errors that were out of specification. In summary, out of 7,999 data entries, 7,400 or 93% of the data sets were within specification, while 599 or 7% of the data sets were out of specification.

USAT Current Error Data

In order to judge the current performance of the USATs, USAT performance data was taken from Devers on 8/10/99, and Lighthipe, Lugo, Mira Loma, Moorpark, and Rector on 8/11/99. In this study, data were obtained from all USATs, both Mod-1 and Mod-2. The Lighthipe station was also included in the study in order to get a complete perspective of the entire

ULTRA-NET^{TM} system. Round Trip data was recorded and plotted in the exact same manner as the previous study. Figure II-2 provides a bar graphs comparing Round Trip error magnitudes vs. frequency for the 8/10/99 to 8/11/99 period.

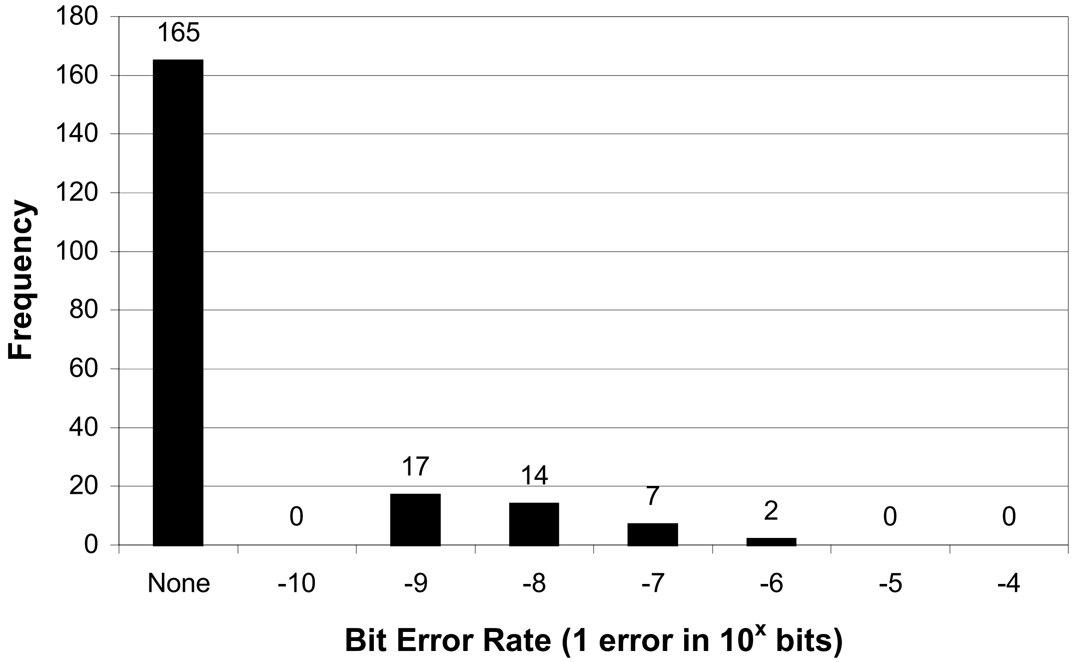

Figure II-2 - USAT Mod-2 Round Trip Bit Error Rate vs. Frequency for 8/10/99 and 8/11/99

For the 8/10/99 to 8/11/99 time period, using the conservative BER specification (1×10^{-7}), 10 out of a total of 207 units or 5% were determined to be out of specification When the regular error specification of 1×10^{-6} is used, this number drops to 3 or 1.5% of the units out of specification.

Out of a total of 207 units and using the conservative BER specification (1×10^{-7}), 166 units (80%) showed no errors, 31 units (15%) showed errors that were within specification, and 10 units (5%) showed errors that were out of specification. In summary, out of 207 units, 197 of the units (95%) were within specification, while 10 (5%) were out of specification using the more stringent BER specification.

When this data is compared against the official BER specification (1×10^{-6}), 166 units (80%) showed no errors, 38 entries (18%) showed errors that were within specification, and 3 units (1.5%) showed errors that were out of specification. In summary, out of 207 units, 204 or 98.5% of the units were within specification, while 3 or 1.5% of the units were out of specification.

Proportion Test

In order to compare the current performance of the USATs (8/10/99 and 8/11/99) with the 10/98 to 7/99 time period, a two-sample proportion test was conducted. Actual calculations for the test were performed using Statistix for Windows analytical software. It should be noted that the 10/98 to 7/99 sample data contains BER readings from Mod-2 USATs from Devers, Lugo, Mira Loma, Moorpark, and Rector, while the 8/10/99 and 8/11/99 data contains data from both Mod-1 and Mod-2 USATs from Devers, Lighthipe, Lugo, Mira Loma, Moorpark, and Rector.

Through the proportion test, it was shown that the USAT BERs for the 8/10/99 and 8/11/99 time period were significantly lower than the 10/98 to 7/99 test period.

Appendix III
New Transmitter-Receiver Card Test Report

Introduction

Southern California Edison and Wasatch Aerospace Company conducted tests of the new transmitter-receiver card at the Mira Loma Regional Control Center over a four-day period from October 25 through 28, 1999. These tests used the new Mod-2 hub with the new transmitter-receiver card installed. The new demodulator card was also installed, but testing was not possible because some software was incomplete.

Test Objectives:

- Install and establish Mod-2 ULTRA-NET™ hub and Ultra Small Aperture Terminal (USAT) communications.
- Demonstrate communications between the Mod-2 Hub and the USAT at a data rates of 0.6 kbps, 1.2 kbps, and at 9.6 kbps with 255 kHz and 1025 kHz outbound bandwidths.
- Establish the minimum signal strength point at which the USAT fails to track the hub signal.
- Establish signal-to-noise ratios at the FCC transmit power maximum limit.
- Determine the Bit Error Rate.
- Demonstrate successful transmission and receipt of the Control Data Corporation (CDC) commands.

The Mod-2 hub was installed at the Southern California Edison (SCE) Mira Loma Regional Control Center (RCC). The radio frequency (RF) connections of the hub were made to the existing satellite outdoor equipment and antenna. This was done in parallel with the Mod-1 operational hub at this RCC site. The new embedded computer was connected to the new Mod-2 hub indoor equipment. The RS-232 port on the embedded computer was connected to a SCADA master test set, emulating the Harris SCADA master interface through a modem connection using CDC protocol.

A Mod-2 USAT was installed, powered up, and made operational on the new Mod-2 Hub. This provided a complete end-to-end connection for the Mod-2 Hub. The Mod-2 hub had all the components of a complete hardware prototype chain involving a Transmit/Receive card, demodulator card, hub computer, and monitor with an NT operating system. The entire system worked as planned.

Test Results

The RF transmit spectrum was checked to verify that the hub transmit synthesizer was operating at the right frequency and that the bandwidth utilized was consistent for the full range of data rates from 0.6 kbps to 9.6 kbps. At 9.6 kbps, the spectrum was also checked for both the 255 kHz and 1024 kHz spread spectrum bandwidths or code lengths.

Tests were conducted to determine the minimum signal strength at 0.6 kbps at which signal track with the satellite was lost. The diagnostic metrics were noted at this signal/noise ratio, which was 14.1 dB. Initially, the metrics turned out to be a factor of three above projected levels. The spectrum analyzer was used to check the transmit pattern. A small spur was detected, causing the very high digital data and phase-related measurements. The problem was fixed after eliminating the synthesizer spur.

Two of the four command packets at the 0.6 kbps data rate were found to be in error for every command update. This was traced to a data formatting error. The error rate at 0.6 kbps was zero for short-term measurements. The Mod-2 USAT hub power output was measured with an 18 dB hardware attenuation and a 19 dB software attenuation in place. The predicted design output power of -23.8 dBm was measured at the indicated total attenuation. The Mod-2 USAT lost track of the satellite at this attenuation level.

Ten dB of attenuation was then removed and no short-term errors were experienced at the signal/noise ratio of 23.0 dB. However, the system metrics were still about twice the projected design level. With the hub attenuation at 9.0 dB, the transmit power was -14.5 dBm as expected.

With the outbound hub transmit signal at the FCC threshold of -6 dBw/4 khz, the signal/noise ratio at 0.6kbps was about 28 dB and the system metrics approximately a factor of two higher than projected. The hub output power was -9.8 dBm at a hub attenuation level of 4 dB.

The above tests were repeated at a data rate of 9.6 kbps and a transmit bandwidth of 255 kHz. At a power spectral density of -6 dBw/4 khz, the Mod-2 USAT terminal signal-to-noise ratio was 20.3 dB with the hub attenuation at 10 dB and a transmit power level of -15.2 dBm. This was the predicted design level data.

The hub attenuation level was then increased by 9 dB. The resulting signal/noise level of 12.5 dB was as predicted by design. This was the satellite loss-of-tracking threshold power level corresponding to the 0.6 kbps case. The data verified the projected design level satellite tracking loss threshold at 9.6 kbps and 255 kHz bandwidth.

Tests were repeated for the 9.6 kbps data rate and 1024 kHz transmit bandwidth. The data correctly matched the projected levels corresponding to the 0.6 kbps baseline design.

Performance Tests for Mod-2 ULTRA-NET™ Hub

Two twelve-hour performance tests were conducted to determine the error rates at the 9.6 kbps data rate and transmit bandwidths of 255 kHz and 1024 kHz. Only two errors were noted at the end of each performance run. This confirmed a projected bit error rate (BER) of 6.02×10^{-9} with 240 bytes transmitted per packet.

Other tests were run and results obtained as follows:

- CDC commands sent through the hub were received at the USAT without error.
- Trip/close commands were sent through the hub and routed to the correct USAT without error.
- Different command sequences were sent per the CDC protocol and were all received by the USAT from the Mod-2 hub without error.
- CDC scan requests were sent and pre-established data were received at the USAT without error.
- The CDC protocol was 100% successfully tested.

As noted on the spectrum analyzer for both the wide and narrow-band hub transmissions, the USAT Mod-2 hub is fully compliant with FCC regulations.

Appendix IV
Network Monitoring System with TCP/IP Protocol Test Report

Introduction

The previous version of the hub required that the operator be at the satellite hub to look for system status. Problems with the satellite system were only detected when data was not received by the utility's transmission SCADA system. To eliminate this issue, a network management system was designed so messages about satellite system problems could be communicated back to a central point. Since it is becoming increasingly common for utilities and other companies to operate a Transmission Control Protocol/ Internet Protocol (TCP/IP) network to connect their vital communication nodes, this was the communication method selected for the network management system. These messages about satellite system problems can be received by a central network management system or any other computer on the network. The messages are constructed using simple American Standard Code for Information Interchange (ASCII) strings to make decoding easy. There are three levels of warnings to indicate a failure, need for maintenance, or component degradation in the satellite communication system. The determination is made by the hub software using status information received from each USAT as part of normal polling process. Hub status information is also used to diagnose problems internal to the hub itself. The main goal of this system is to identify problems with the satellite system as quickly as possible, and dispatch personnel to make the needed repairs.

TCP/IP Interface

For the new Mod-2 satellite hub, Ethernet was chosen for the communications media. At SCE, Ethernet is used to connect most devices and computers to the company LAN/WAN. At the present time, 10BaseT is the standard connection. Since the hub embedded computer is running on Windows NT, the standard TCP/IP stack was used for communications. The network management messages were packaged in an unacknowledged packet using the UDP standard. These packets were then sent over the network to a specified IP address. At this device, the UDP package was stripped off and the original network management message recovered. The message can be sent to any address required with a simple change in the IP address.

Operation of the Network Management System

Initially, use of Simple Network Management Protocol (SNMP) protocol was investigated for use in sending messages to the central network management system. After some investigation, it was determined that Windows NT did not support SNMP as well as required for the satellite hub implementation. The SCE network management group was consulted, and it was determined that the best format for the network management messages was simple ASCII strings embedded in a UDP packet.

The network management message data stream was defined as follows:

- Packet Sequence Number - 4 characters
- Problem Device ID number - up to 7 characters
- Urgency Type number - 1 character
- Type Of Failure message - up to 31 characters
- Hub ID Number affected by the problem - up to 5 characters
- Hub Location Name - up to 10 characters

- USAT Location Name - up to 15 characters

The message length is up to 79 characters, including 6 comma delimiters. An example of the packet structure is:

9999,0005125,1,rtu experiencing packet loss,05000,Mira Loma,Canyon Sub

The data fields used in this message are:

- Packet Sequence Number (9999): a field that is used internally to help track problems on the ULTRA-NET™ system.
- Problem Device ID (0005125): a system ID number that identifies the problem device (USAT or satellite hub).
- The Urgency Type (1) is a character with three possible values: 1 means a failure of the problem device; 2 means the problem device is degraded, but has not failed completely; and 3 means the problem device will need service soon.
- The Type of Failure message (rtu experiencing packet loss) is a text string that defines the type of failure that occurred. This string is displayed as it is received from the satellite hub.
- The Hub ID Number (05000) identifies which satellite hub is associated with the problem device. If the hub is the problem device, the Problem Device ID will be the same as the Hub ID.
- The Hub Location Name (Mira Loma) is a text string that translates the satellite Hub ID number into a human readable location identifier.
- The USAT Location Name (Canyon Sub) is a text string that translates the Problem Device ID number into a human readable location identifier.

The above information is used by the central network management system to decode the network management messages. The central network management staff has been given a list of phone/pager numbers to call when various types of problems are encountered.

System Testing

The network management software was integrated into the software running on the NT-embedded computer in the satellite hub. For the system testing, a second computer, utilizing software that receives and displays the network management message, was connected to the first using a standard Ethernet hub. Because the satellite hub is not in full operation (only transmit capability), a drop-down menu item was added to the satellite hub software to initiate sending a network management alert message. Whenever this menu option is selected, a message is assembled, encapsulated in a UDP packet, and shipped over the Ethernet interface. The second computer, the receiver, listens for messages directed to its IP address. When it receives a message, the network protocol information is stripped off and the message parsed and sent to the screen.

Testing Results

Using the test setup mentioned in the previous section, network management messages were initiated from the satellite hub and received at the monitoring computer. Single messages were sent, as well as a series of messages back-to-back. In all cases, all messages were received and decoded properly. When the satellite hub is in complete operation (both transmit and receive capability), the same tests will be rerun. With the hub in full operation, real events can be simulated and messages sent. In addition, testing should be done with the actual SCE network management system. This will take some software modifications by SCE to properly parse the network management messages.